TITLE: Analysis of Heart Rate Variability During Sleep as a Tool for Assessment of Cardiovascular Adaptability and Fatigue in Sleep-Wake Cycle

Analysis of Heart Rate Variability during Sleep as a Tool for Assessment of Cardiovascular Adaptability and Fatigue in Sleep-Wake Cycle

G. Varoneckas
Institute of Psychophysiology and Rehabilitation
c/o Kaunas Medical University
Vyduno Str. 4,
5720 Palanga, Lithuania

Summary

An assessment of general adaptation reserve of cardiovascular function by means of heart rate (HR) and HR variability analysis during sleep and functional tests is demonstrated. A possibility to evaluate a restoration of cardiovascular reserve after sleep by means of HR changes during active orthostatic test is shown. The level of autonomic HR control and balance of sympathetic-parasympathetic inputs might be measured by means of analysis of HR power spectrum main oscillatory components. The differences in cardiovascular reserve of healthy subjects and cardiac patients, as well as possibility of HR restoration during sleep was demonstrated. *In conclusion.* Adaptability of cardiovascular function and fatigue–restoration cycle might be assessed by means of very simple methodology – an analysis of HR Poincare maps. Its practical application in the cases of fatigue, developed during disturbed wake-sleep cycle or overtraining situation in high physical or emotional overcrowding is shown.

INTRODUCTION

Evaluation of cardiovascular adaptability e.g. cardiovascular functional reserve, as well as evaluation of fatigue, might be seen as very important aspects in organization of day-night activities for military staff (at home and fight missions) and for appropriate work of civil operators, especially in the cases of shift work or disturbed sleep-wake cycle.

Autonomic control of cardiovascular function, being a main adaptability definitive characteristic, consists of two main components, tonic and reflex autonomic control [2, 11]. Tonic control of cardiac function might be assessed by a measurement of heart rate (HR) variability at rest, while reflex control was ascribed by several HR responses to tests, involving exercise or shifts of sleep stages, related to baroreflex control [2, 6, 9, 10, 11, 16]. Between of the tests might be mentioned an active orthostatic test (AOT), submaximal or symptom limited exercise, medicamental tests, as well as sleep with a natural changes of autonomic control during shifts of sleep stages and cycles [6, 17, 20, 21].

Night sleep with modifications in functional state of autonomic nervous system during shifts of sleep stages and cycles is responsible for modification of HR variability and its periodical structure, reflecting particular domination of sympathetic or parasympathetic control at individual sleep stage [1, 7, 8, 13, 15, 19, 20, 21]. From the other hand, normal sleep was responsible for restoration of functional state of nervous system, regulating all organism functions, particularly of cardiovascular function, after of their activation or exhaustion during daily activities or mission action.

Working hypothesis is that assessment of HR frequency and variability changes during night sleep and functional tests (exercise, AOT) might be used as a measure of adaptability of cardiovascular system e.g. for evaluation of fatigue or restoration after it in healthy subjects (H Ss) or cardiac patients.

The goal of the study was an assessment of general adaptation reserve of cardiovascular function by means of HR analysis during sleep and functional tests, as well as a demonstration of possibility to evaluate a restoration of cardiovascular reserve during sleep by means of HR changes during active orthostatic tests, performed just before and after sleep.

METHODS

Computerized analysis of HR frequency and variability in parallel to hemodynamics (measured by impedance cardiography) was performed during night

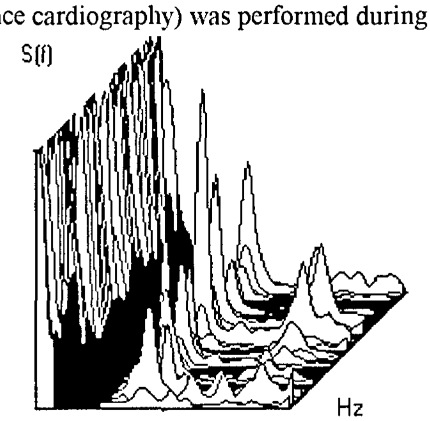

Fig. 1. An example of HR running spectra during individual night sleep stages.

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sleep and functional tests such as active orthostatic test at day-time, evening-time and morning-time, as well as, during exercise, using bicycle-ergometry test, reaching submaximal HR frequency or symptoms limiting exercise. Sleep stages and cycles have been identified using conventional polysomnography. HR power spectrum by means of Furje analysis, including running spectra (Fig. 1) was used for identification of three main oscillatory components: very low frequency component (VLFC), related humoral control, low frequency component (LFC), due to more sympathetic one, and high frequency component (HFC), reflecting parasympathetic control [3, 12, 18, 19].

For evaluation of total cardiovascular reserve was used a simple methodology of non-linear dynamic – Poincare map (or return map) of HR with analysis of relationship between of consecutive interbeat intervals (RR_i and RR_{i+n} sequence, while n = 1), recorded during shifts of sleep stages and cycles, as well as during active orthostatic test, or increasing physical exercise, or all of them collected together (Fig. 2).

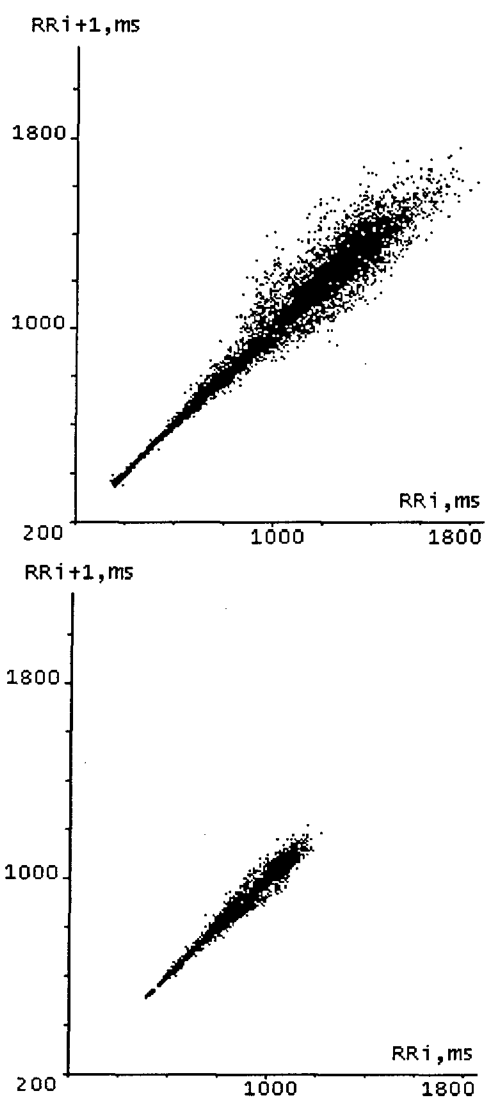

Fig. 2. An examples of Poincare maps of RR intervals, collated during sleep and exercise test in healthy Ss (top) and IHD pt (bottom).

The contingent was 40 H Ss and 153 ischemic heart disease patients (IHD pts). H Ss and IHD pts were distributed into the subgroups according to HR frequency baseline level at rest during waking state just before sleep (RR < 1.0 s, RR ≥ 1.0 s). IHD pts were distributed also according to their HR responses to sleep stages: typical (the same as for H Ss) and reduced HR responses to shifts of sleep stages (HR responses less than 5% from baseline level).

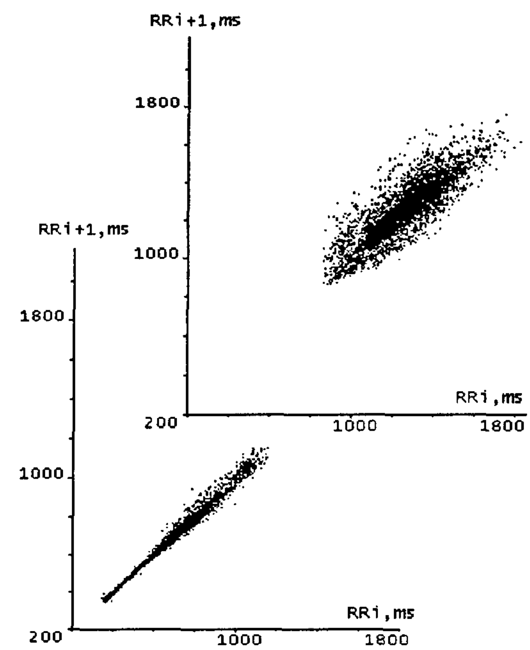

Fig. 3A. An examples of Poincare maps of RR intervals during sleep (top) and exercise (bottom) in healthy Ss.

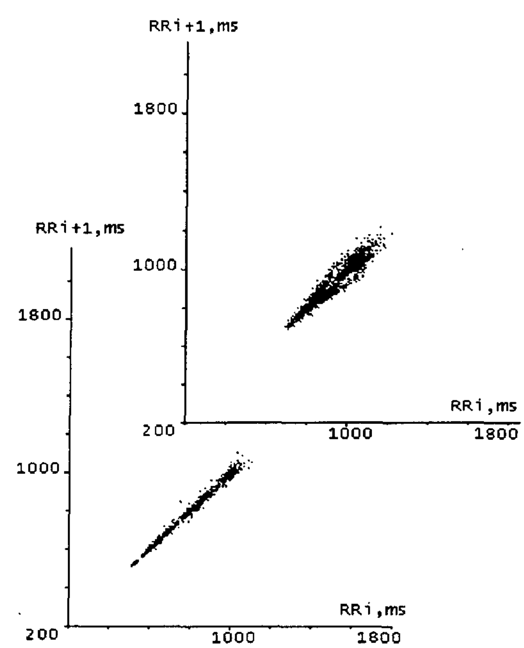

Fig. 3B. An examples of Poincare maps of RR intervals during sleep (top panel) and exercise (bottom) in IHD pts.

RESULTS AND DISCUSSION

Adaptability of cardiovascular function

HR frequency and HR variability at rest might be seen as reflecting prevalence of sympathetic or parasympathetic HR control, while maximal HR responses to all tests (sleep stages and exercise) were reflecting a total level of HR adaptation reserve for particular subject at a current its functional state Figure 2 demonstrates significant difference between of prevalence of parasympathetic HR control at rest (maximal HR variability during night sleep) for H Ss and IHD pts.

From the other hand, Poincare maps, presented in Figure 2, reflect maximal level of HR frequency changes during all tests, which might be used as a measure of adaptability. It was much more expressed for H Ss (ΔRR = 1400 ms): between of minimal HR value during slow wave sleep (RR $\cong$ 1750 ms) and maximal one during peak exercise (RR $\cong$ 350 ms). For IHD pts its total level of adaptability was twice as low (700 ms), HR being less low at minimal level during sleep (1200 ms) and less high at maximal one during exercise (500 ms). Thus, reduction of HR maximal response in IHD pts might be

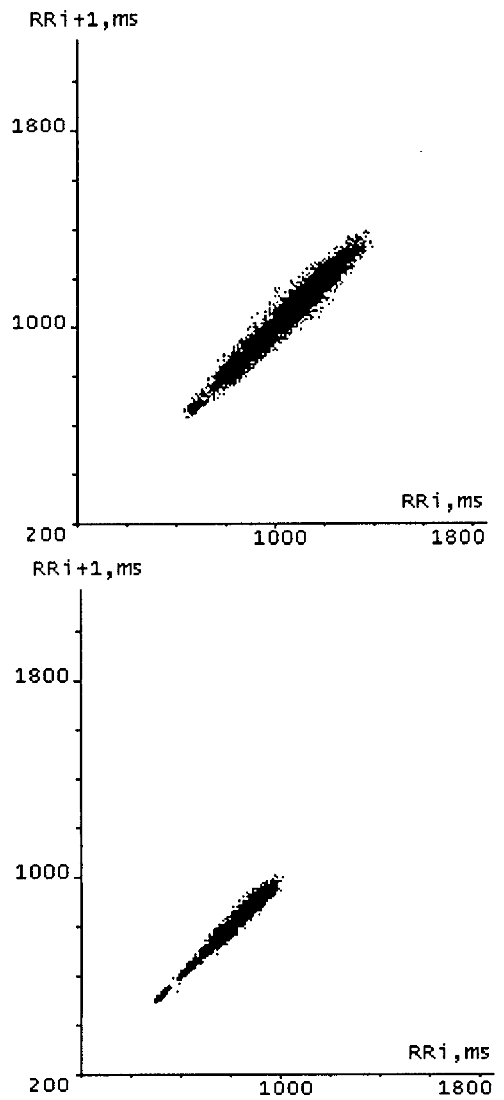

Fig. 4. An examples of Poincare maps of RR intervals, collated during sleep and exercise test in IHD patient with leading hypertension (top) and patient with leading congestive heart failure (bottom).

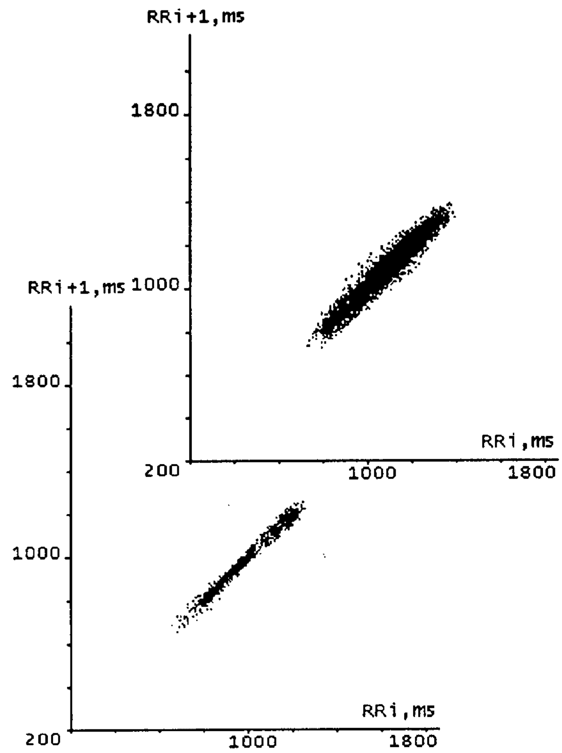

Fig. 5A. An examples of Poincare maps of RR intervals during sleep top panel) and exercise (bottom) in IHD pt.

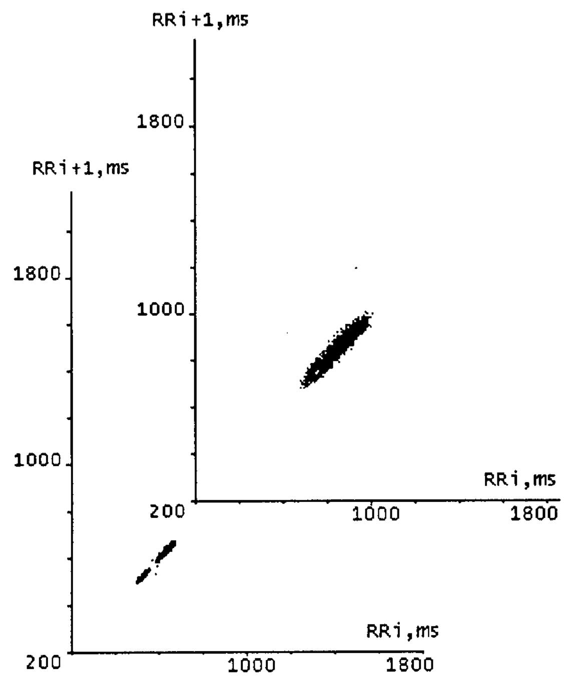

Fig. 5B. An examples of Poincare maps of RR intervals during sleep (top panel) and exercise (bottom) in IHD pt.

related to reduction of HR control from both sides, parasympathetic and sympathetic control.

Figure 3 demonstrates an evaluation of HR adaptability reserve for H Ss (Fig. 3A) and IHD pts (Fig. 3B), while HR recording used during sleep only (top panel) and during waking rest–exercise only (bottom). In both situations of testing H Ss demonstrated more wide adaptability reserve than IHD pts. For H Ss it was more expressed during sleep than during exercise, while in IHD pts this difference shown opposite direction – it was lower in sleep, demonstrating reduction of central parasympathetic control.

Figure 4 demonstrates the differences of HR adaptability reserve in two IHD pts with the same NYHA functional class: the patient with leading hypertension (top panels of Fig. 4 and Fig. 5A) shown more wide adaptability reserve, than patient with congestive heart failure after myocardial infarction, having reduced HR response during the shifts of sleep stages and exercise test: ΔRR with of 900 ms in the first one and 450 ms in the second one, correspondingly. If evaluated separately HR adaptation reserve was more high during sleep (ΔRR ≅ 600 ms) than exercise (ΔRR ≅ 400 ms) for the first patient, while opposite situation was for the second one (ΔRR ≅ 300 ms during sleep and ΔRR ≅ 400 ms during exercise). From the other hand, HR frequencies in sleep and exercise were not overlapping, as it was seen for H Ss and for the rest of the patients with congestive heart failure.

Thus, evaluation of adaptability of cardiovascular function, while measured as total HR responses during sleep and exercise should provide important information about the functional reserve of investigated persons. Although, while measured separately during night sleep and functional tests at waking state, Poincare maps might dispose a supplementary information, about the which branch, sympathetic or parasympathetic, of HR control was more involved in to the process of adaptation.

Restoration of Cardiovascular Function during Sleep

In the cases of fatigue, developing during disturbed wake-sleep cycle or overtraining situation in high physical or emotional overcrowding, as well as, it is in IHD pts due to complications, there might be some differences in HR control restoration during sleep. If cardiovascular function was not able to restore, a fatigue might be increasing during the rest of the day. Such situations might be seen in sportsmen during their training sessions while overstrained [4, 5, 22]. Because of that HR response to AOT were used for evaluation of restoration of their functional status after night sleep [14].

The same methodology was shown as demonstrating positive results for investigation of HR restoration during sleep in IHD pts. Figure 6A demonstrates an increase of HR responses to AOT at morning hours just after sleep (top panel) as compared to day time AOT (bottom) and evening-time (middle panel)

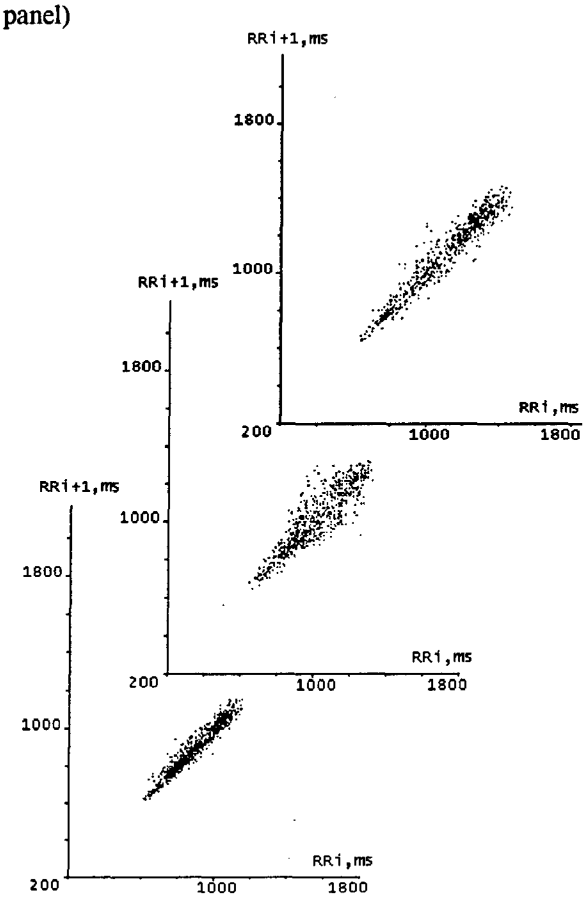

Fig. 6A. An examples of Poincare maps of HR during AOT tests, performed at day-time (bottom), evening-time (middle) and morning-time (top panel) in H Ss.

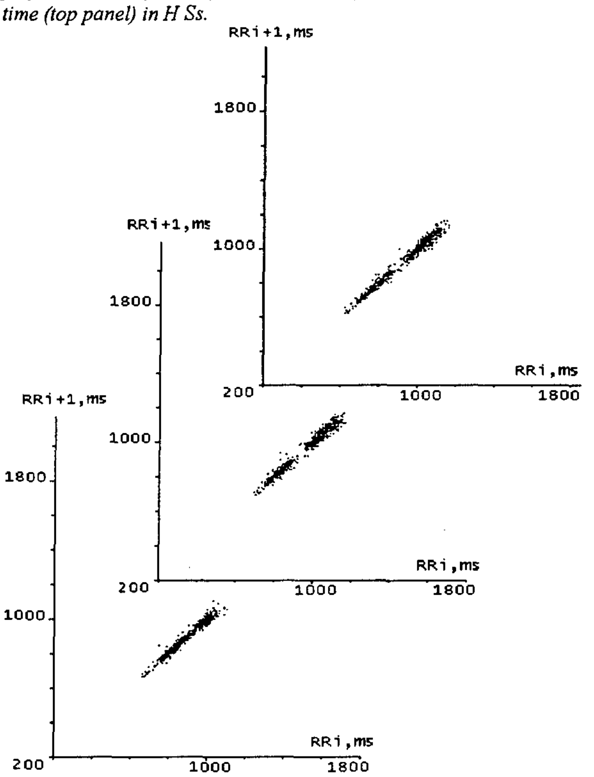

Fig. 6B. An examples of Poincare maps of during AOT tests, performed at day-time (bottom), evening-time (middle) and morning-time (top panel) in IHD pt.

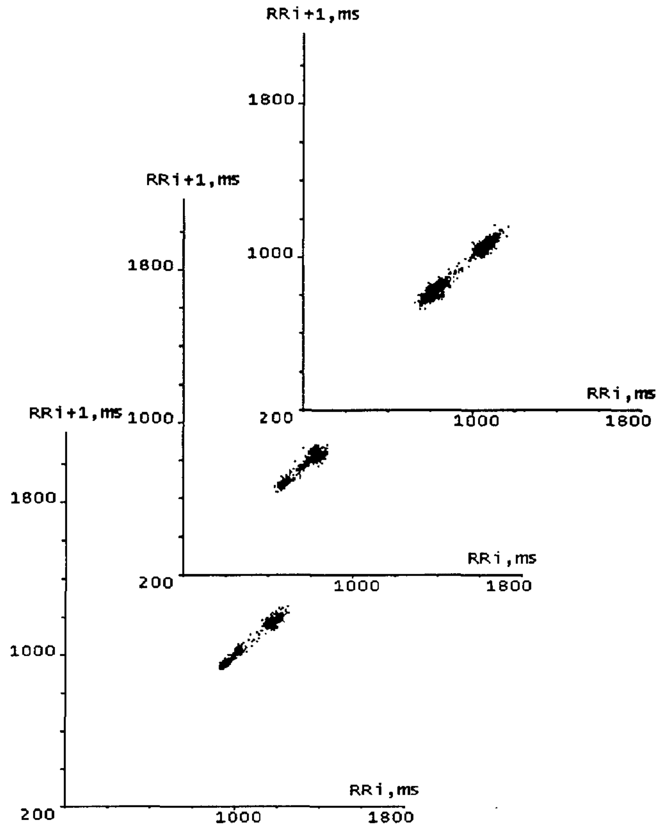

Fig. 7A. An examples of Poincare maps of HR during AOT tests, performed at day-time (bottom), evening-time (middle) and morning-time (top panel) for IHD pt.

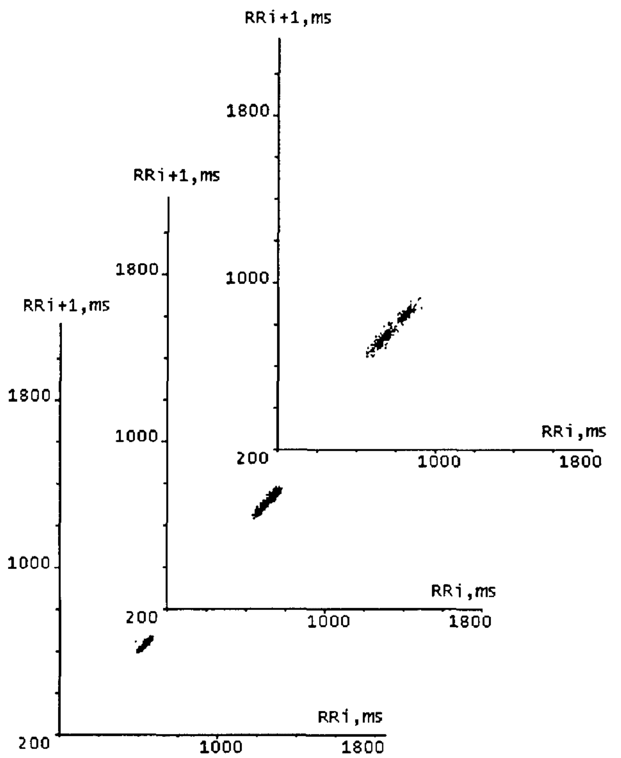

Fig. 7B. An examples of Poincare maps of HR during AOT tests, performed at day-time (bottom), evening-time (middle) and morning-time (top panel) for IHD pt.

for H Ss. The same tendency of HR responses changes were demonstrated for IHD pt (Fig. 6B), although HR changes were less expressed.

The difference of HR restoration after sleep in two IHD pts (shown in Fig. 4) demonstrated some specific differences (Fig. 7A, 7B). In IHD patient HR response to AOT at evening-time was reduced as compared to day-time, although restored after sleep (Fig. 7A). However, in IHD patient with more reduced adaptability reserve (Fig. 7B), despite of very small response of HR to AOT at day-time, a tendency for restoration of HR response after sleep there was still present.

Table 1 demonstrates HR frequency and variability dynamics during sleep, if compared at the first and the last cycles of sleep: there were seen the clear-cut differences of the level of decrease of HR frequency and an increase of HR variability during sleep in relation to initial HR, HR decrease during night was significant only in those with initially increased HR either for H Ss and IHD pts. HR variability changes were related positively to their initial level.

A tendency of negative relationship to baseline HR might be seen in HR changes, while measured just before and after sleep (Table 2). It was true for H Ss and IHD pts, although only for those with typical HR response to night sleep. Although for IHD pts with reduced HR response to sleep there was no differences of HR responses, as compared HR just before and after sleep in the cases with slight prevalence of HR sympathetic control. It was followed by a reduction of HR maximal response to AOT, instead of its increase, as it was in H Ss and total IHD pts group. If initial bradycardia is present in IHD pts with reduced HR pattern during sleep it was followed by non-significant decrease of HR frequency, but increased HR maximal HR response to AOT, being opposite as compared to typical group of IHD pts.

Table 1. Characteristics of HR frequency and variability during the first and the last cycles of sleep in healthy subjects and IHD pts

	First cycle		Last cycle	
	RR, ms	σRR, ms	RR, ms	σRR, ms
Healthy Ss	1093	65	1129	79
RR<1.0 s	954	54	1113	69
RR≥1.0 s	1177	72	1145	86
IHD pts	1026	42	1037	48
RR<1.0 s	934	38	1027	43
RR≥1.0 s	1132	47	1051	54
HRSP typical	1022	52	1051	61
RR<1.0 s	946	49	1042	55
RR≥1.0 s	1098	56	1069	67
HRSP reduced	1032	31	1028	34
RR<1.0 s	906	26	1007	27
RR≥1.0 s	1178	36	1075	41

Thus, an analysis of HR responses to AOT during day activities and just before and after sleep might be important measure of fatigue during a day time and ability of cardiovascular control restoration after sleep. Composition from restoration of HR and hemodynamics control during sleep might be used for creation of more full picture of restoration during sleep either in H Ss and IHD pts. For the latter hemodynamics changes were more important [14, 18, 22], than for H Ss in whom adaptation reserve of cardiovascular system is present and working through autonomic HR control mainly.

Table 2. HR responses to AOT, recorded at day-time, evening-time and morning-time after sleep in healthy Ss and IHD pts

	RR_I, ms	RR_B, ms	ΔRR_B, ms	ΔRR_B, %
		Day-time		
Healthy Ss	980	620	360	36
RR<1.0 s	898	576	304	34
RR≥1.0 s	1053	657	406	38
IHD pts	958	718	248	25
RR<1.0 s	911	664	227	25
RR≥1.0 s	1042	775	271	26
HRSP typical	965	653	281	31
RR<1.0 s	913	621	268	31
RR≥1.0 s	981	691	295	31
HRSP reduced	953	783	186	18
RR<1.0 s	879	693	165	18
RR≥1.0 s	1155	858	204	18
		Evening-time		
Healthy Ss	1085	673	409	37
RR<1.0 s	879	570	309	34
RR≥1.0 s	1144	705	439	38
IHD pts	980	689	301	31
RR<1.0 s	859	617	246	29
RR≥1.0 s	1111	754	350	33
HRSP typical	1017	650	342	33
RR<1.0 s	866	639	261	25
RR≥1.0 s	1065	656	409	37
HRSP reduced	1009	732	295	29
RR<1.0 s	954	609	225	26
RR≥1.0 s	1153	793	330	31
		Morning-time		
Healthy Ss	1082	608	479	43
RR<1.0 s	991	597	394	39
RR≥1.0 s	1123	612	505	44
IHD pts	981	676	323	32
RR<1.0 s	902	636	260	29
RR≥1.0 s	1090	711	379	34
HRSP typical	1004	655	297	31
RR<1.0 s	919	632	265	30
RR≥1.0 s	993	670	323	32
HRSP reduced	1010	671	342	32
RR<1.0 s	954	620	202	24
RR≥1.0 s	1176	703	412	37

CONCLUSIONS

The level of autonomic HR control and balance of sympathetic-parasympathetic inputs might be measured by means of analysis of HR power spectrum components. Adaptability of cardiovascular function and fatigue–restoration cycle might be assessed by means of very simple methodology – an analysis of HR Poincare maps, constructed from consecutive RR intervals, recorded during sleep, exercise, or active orthostatic tests. All tests together enable to evaluated a total level of adaptation reserve of cardiovascular function, using HR responses to all tests. Particular restoration of adaptability, might be evaluated using HR analysis during repetitive active orthostatic tests, performed just before and after sleep.

References

1. Berlad I, Shlitner A., Ben-Haim S., Lavie P. Power spectrum analysis and heart rate variability in stage 4 and REM sleep: evidence for state-specific changes in autonomic dominance. J. Sleep Res. 1993; 2: 88-90.
2. Eckberg D.L., Sleight P. Human Baroreflexes in Health and Disease. Oxford, England: Clarendon Press 1992. 572 p.
3. Januskevicius Z., Kusas V., Zemaityte D. Avtokorrelacijonnuj analiz sinusogovo ritma serdca (Rus.). Cor et Vasa. 1973; 15 (2): 108-120.
4. Kepezenas A., Zemaityte D. Relationship between periodical structure of rhythmogram and work capacity in sportsmen. Electrocardiology'1983. Cardiac Rhythm, arrhythmias, Conduction Disturbances. Bratislava. 1985: 15-17.
5. Kepezenas A., Zemaityte D. Zavisimost struktury sergechnogo ritma ot fizicheskoj rabotosposobnosti sportsmenov v zavisimosti ot charaktera trenirovochnogo processa (Rus.). Fiziologija Cheloveka. 1983; 9 (5): 729-739.
6. Pickering T.G., Gribbin B., Petersen E.S. et al. Comparison of the effects of exercise and posture on the baroreflex in man. Circ. Res. 1971; 5: 582-586.
7. Pivik R.T., Busby K.A., Gill E., Hunter P., Nevins R. Heart rate variations during sleep in preadolescents. Sleep. 1996; 19, 2: 117-135.
8. Shinar Z., Baharav A., Sivan Y., Akselrod S. REM sleep autonomic nervous activity investigated by heart rate variability in the taime domain. Sleep. 1999; 22 (1): S19-S20.
9. Sleight P., Casadey B. Relationships between heart rate, respiration and blood pressure variabilities. In Malik M., Camm A.J., editors. Heart Rate Variability. Armonk , N.Y., Futura Publishing Company, Inc., 1995: 311-327.
10. Spyer K.M. Neural organization and control of the baroreceptor reflex. Rev. Physiol. Biochem. Pharmacol. 1981; 88: 23-124.
11. Spyer K.M. The central nervous organization of

reflex circulatory. In Loewy A.D., Spyer K.M., editors. Central Regulation of Autonomic Functions. New York, N.Y., Oxford University Press, 1990: 168.

12. Ulbikas, J., Cenys, A., Zemaityte, D., Varoneckas, G. Nonlinear dynamics in heart rate data. Building Bridges in Electrocardiology. Eds. van Oosterom, A., Oostendorp, T.F., Uijen, G.J.H.. Proceeding of the XXIInd International Congress on Electrocardiology. Nijmegen. The Netherlands. 25-29 June. 1995. Nijmegen. University Press Nijmegen. 1995: 216-217.
13. Vanoli E., Adamson P.B., Ba-Lin, Pinna G.D., Lazzara R., Orr W.C. Heart rate variability during specific sleep stages: A comparison of healthy subjects with patients after myocardial infarction. Circulation. 1995; 91: 1918-1922.
14. Varoneckas, G., Dauksys, R., Zemaityte, D. Restoration of cardiovascular function during sleep in relation to physical fitness in coronary artery disease patients with congestive heart failure. Electrocardiology' 98. Ed. Preda I. Proceedings of the XXVth International Congress on Electrocardiology. Budapest, Hungary. 3-6 June. 1998. World Scientific: Singapore·New Jersey·London·Hong Kong. 1998: 327-330.
15. Vaughn B.V., Quint S.R., Messeinheimer J.A., Robertson K.R. Heart period variability in sleep. Electroencephalography and clinical Neurophysiology. 1995; 94: 155-162.
16. Zemaityte, D., Varoneckas, G., Dilkaite, V., Martinkenas, A. Baroreflex sensitivity and heart rate variability. Electrocardiology' 97. Eds. Bacharova, L., MacFarlane, P.W. Proceedings of the XXIVth International Congress on Electrocardiology. Bratislava, Slovak Republic. 24-28 June. 1997. World Scientific: Singapore·New Jersey·London·Hong Kong. 1998: 85-88.
17. Zemaityte, D., Varoneckas, G., Ozeraitis, E. Noninvasive computerized analysis of heart rate variability and dysrhythmias in relation to their hemodynamic effect. Building Bridges in Electrocardiology. Eds. van Oosterom, A., Oostendorp, T.F., Uijen, G.J.H.. Proceeding of the XXIInd International Congress on Electrocardiology. Nijmegen. The Netherlands. 25-29 June. 1995. Nijmegen. University Press Nijmegen. 1995: 208-209.
18. Zemaityte, D., Varoneckas, G., Ozeraitis, E., Zakarevicius, L., Valvoniene, V. Evaluation of autonomic heart rate control and hemodynamic responses to different tests using computerized rhythmography and impedance cardiography. Proceedings of the IX International Conference on Electrical Bio-Impedance In conjunction with the European Community Concerted Action on Impedance Tomography. Eds. Gersing, E,. Schaefer, M. Heidelberg. Germany. September 26-30. Heidelberg. 1995: 192-195.
19. Zemaityte, D., Varoneckas, G., Plauska, K., Kaukenas, J. Components of the heart rhythm power spectrum in wakefulness and individual sleep stages. Int. J. Psychophysiology. 1986; 4 (2): 129-141.
20. Zemaityte, D., Varoneckas, G., Sokolov, E. Heart rhythm control during sleep. Psychophysiology. 1984; 21 (3): 279-289.
21. Zemaityte, D., Varoneckas, G., Sokolov, E. Heart rhythm during sleep in ischemic heart disease. Psychophysiology. 1984; 21 (3): 290-298.
22. Zhemaitite, D., Kepezhenas, A., Martinkenas, A., Podlipskite, A., Varonetskas, G., and Zhilyukas, G. Age-related relationship of cardiac rhythm and blood flow parameters in healthy subjects and patients with cardiovascular diseases. Human Physiology. 1998; 6 (24): 701-710. Translated from Fiziologiya Cheloveka. 1998; 6 (24): 56-65.